

# COREX & FINEX - NEW DEVELOPMENTS IN UTILIZATION OF LOW GRADE RAW MATERIALS

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## ABSTRACT:

*The COREX&FINEX technology are the recent economic and ecologic industrial realized alternative to the blast furnace route for the production of hot metal. By fulfilling more stringent ecological regulations by law, utilization of low-cost/high-available low grade raw materials including fine, these processes approve themselves as reasonable technologies for present and future iron making process.*

*This paper gives an overview about the COREX& FINEX plants in operation, shows the new developments and findings for the COREX& FINEX process and depicts valuable concepts for the utilization of the COREX export gas.*

*And experiences with new developments already applied and proven on operating plants.*

**Keywords:** New Developments In Iron Making Process, Smelting Reduction Technology, Overview Of COREX Plant In Operation, Development In Operating Plants, Ecological Regulation.

## 1. INRODUCTION

Global demand for iron and steel is constantly growing, while at the same time prices for raw materials, energy, and transportation is continuously increasing. The requirements of iron making processes are to go compatible with the present ecology and environmental criteria of the region. In this modern environment completely new strategies are required for iron making process. New iron making processes have been extensively explored with a view to saving resources and energy, as well as reducing environmental pollution.

The present scenario of iron and steel sector is very much challenging. Consolidation of the iron and steel branches manifested itself in a significant increase of mergers and takeovers. Nevertheless, the global iron and steel industry continues to expect strong growth. According to the latest analysis, demand for steel will grow by up to 25% by the year 2015, mainly due to rapid economic development in the highly populated Asian countries. In addition to transport and logistics, above all, raw materials and energy are the global driving forces behind the market's dynamics. Energy costs will also continue to increase.

Growing environmental consciousness also contributes to market dynamics by attempting construction of plants that meet increasingly stringent environmental standards. However, existing plants that produce hot metal must continue to optimize their consumption parameters in the future to achieve increased quality with constant or even lowered operation costs. Today a plant for hot metal and/or DRI production is much more than just a plant. It is part of the entire value added chain in iron and steel production.

We've succeeded in developing new processes for producing iron and steel that are more environmentally compatible. The initiative was to create a life cycle assessment for the

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manufacture of pig iron using the COREX and FINEX processes. In contrast to a blast furnace, COREX& FINEX requires neither coke nor sinter to produce pig iron from iron ore. Neither process involves a coking or sinter plant. This means that capital investment and production costs are both lower than with classic blast furnaces, and fewer resources are consumed.

## **2. NEW DEVELOPMENTS IN IRON MAKING PROCESS**

Iron units in various forms are required for making steel. Blast furnace hot metal and recycled steel in the form of scrap have been the main sources of iron. As a consequence of a tight raw material supply

for the blast furnace, the COREX process enables operators to produce hot metal based on raw materials that are still not tight in supply and are available at "reasonable" prices. However blast furnace hot metal production has decreased over the year due to the availability of high-grade metallurgical coke. All these factors have contributed towards the development of alternative technologies to produce iron. So process are available to produce solid iron in form of DRI(Direct reduced iron),SR(Smelting Reduction).

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**2.1. Direct reduced iron** is a process in which iron ore is reduced to the solid state or by gaseous reducing agent. The final product from DRI is solid.

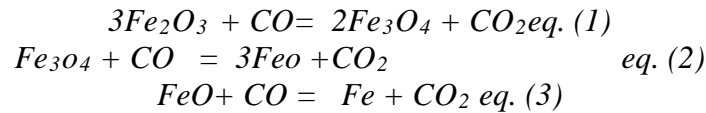
**2.2. Smelting reduction technology** is an alternative technology to the conventional blast furnace. The blast furnace has been the dominant technology for iron production for centuries. Its operation has been improved and optimised continually; this has resulted in very efficient large-scale operating facilities. In addition to smelting reduction technology, direct reduction technology is a second alternative technology to the conventional blast furnace route. Direct reduction technology was explored as a possible replacement for the dominant blast furnace before R&D interest in smelting reduction technology emerged. It is a coal-based ironmaking process and thus different from the conventional coke-based conventional blast furnace. The production of coke is avoided. Most smelting reduction processes also avoid the agglomeration of iron ore. Smelting reduction technology, as the name clearly suggests, involves both solid-state reduction and smelting. Smelting is melting involving chemical reduction reactions. Smelting reduction technology exploits the principle that coal can be gasified in a bath of molten iron gives a schematic lay-out of smelting reduction technology.

Figure 1: Schematic lay-out of smelting reduction technology.

Smelting reduction technology consists of two vessels or two zones, a pre-reduction unit and a smelting reduction vessel. Smelting reduction technology, however, does not necessarily require two separate vessels. The coal is fed into the smelting reduction vessel where it is gasified. This delivers heat and hot gas containing carbon monoxide. The heat is used for melting the iron in the smelting reduction vessel. The hot gas is transported to the pre-reduction unit and used for pre-reducing the iron oxides (in a solid state), which are fed directly into the pre-reduction unit. The pre-reduced iron is subsequently transported to the smelting reduction vessel, where final reduction takes place. The hot gas produced in the

smelting reduction vessel has high chemical energy content due to the presence of carbon monoxide. This can be exploited in two ways. First of all, the carbon monoxide can be used for the reduction of iron oxides in the pre-reduction unit. The hot gas generated in the smelting reduction vessel is transported directly to the pre-reduction unit. Secondly, the carbon monoxide can be oxidised in the smelting reduction vessel, which then delivers more heat. This can be used for smelting the iron. This is called post-combustion.

The initial reduction of iron oxide begins in the temperature ranges of 850°C to 1050°C. The basic reaction involved is as follows:



The carbon monoxide required for reduction:



After post-combustion, the hot gas is transported to the pre-reduction unit and the remaining carbon monoxide is used for pre-reducing the iron oxides. The richness of carbon monoxide in the hot gas determines the degree of pre-reduction in the pre-reduction unit. As post-combustion decreases the reduction potential of the hot gas, compromises have to be made between the degree of post-combustion and the degree of pre-reduction. If the degree of post-combustion is low, higher pre-reduction degrees are achieved in the pre-reduction unit. The product delivered to the smelting reduction vessel is quite similar to the reduced iron that is produced in direct reduction technology, namely direct reduced iron (DRI). More coal is needed in the smelting reduction vessel to melt the iron. Processes operating at such a high level of pre-reduction are referred to as first generation processes. The COREX process is the best known first generation process.



SIMETAL Corex process combines coking plant, sinter plant and blast furnace into a single iron making unit.

### 3. OVERVIEW OF COREX PLANT IN OPERATION

In the COREX process, all metallurgical work is carried out in two separate process reactors. In the first step the iron ore is reduced in a shaft furnace. In second step the reduced iron ore is melted in the melter-gasifier using the energy generated from the gasification (and partial combustion) of coal. The reducing gas produced in this second stage is used in the shaft furnace.

#### 3.1. COREX Process

COREX consists of two reactors, the reduction shaft and the melter-gasifier. The reduction shaft is placed above the melter-gasifier and reduced iron bearing material descends by gravity. The volume of the reduction shaft and the melter-gasifier is about 600 m<sup>3</sup> and 2200 m<sup>3</sup> respectively.

#### 3.2. Reduction Shaft

Iron ore, pellets and additives (limestone and dolomite) are continuously charged into the reduction shaft via lock hopper system located on the top of the shaft. Some amount of coke is also added to the shaft to avoid clustering of the burden inside the shaft due to sticking of

ore/pellets and to maintain adequate bed permeability. The reduction gas is injected through the bustle located about 5 meters above the bottom of the shaft at 850°C and over 3-bar pressure. The specific reduction gas flow is about 1200Nm<sup>3</sup>/ton of iron bearing burden charged to the shaft. The gas moves in the counter current direction to the top of the shaft and exits from the shaft at around 250°C. The iron bearing material gets reduced to over 95% metallization in the shaft and is termed as DRI. Subsequently, six screws discharge the DRI from the reduction shaft into the melter-gasifier.

The metallization degree of the DRI and the calcination of the additives are strongly dependent on the following parameters:-

- Amount and quality of the reduction gas flow,
- Temperature of the reduction gas,
- Reducibility of the iron bearing burden,
- Average particle size and the distribution of the solids charged.

### 3.3. Melter-Gasifier

The melter-gasifier can largely be divided into three reaction zones

- Gaseous free board zone (upper part or dome),
- Char bed (middle part above oxygen tuyeres),
- Hearth zone (lower part below oxygen tuyeres)

Due to continuous gas flow through the char bed, there also exists a fluidized bed in the transition area between the char bed and the free board zone. The hot DRI at around 600-800°C along with partially calcination of limestone and dolomite are continuously fed into the melter-gasifier through DRI down pipes. The DRI down pipes are uniformly distributed along the circumference near the top of the melter-gasifier so as to ensure uniform distribution of material over the char bed. Additionally non-coking coal, quartzite and required quantity of coke are continuously charged by means of lock hopper system. The operating pressure, in the melter-gasifier is in excess of 3 bars. Oxygen plays a vital role in COREX process for generation of heat and reduction gases. It is injected through the tuyeres, which gasifies the coal char generates CO. The hot gases ascend upward through the char bed. The sensible heat of the gases is transferred to the char bed, which is utilized for melting iron and slag and other metallurgical reactions. The hot metal and slag are collected in the hearth. The efficiency of the furnace depends largely on the distribution of this gas in the char bed and utilization of the sensible heat of the gas. The dome temperature maintained between 1000°C to 1100°C, which assures cracking of all the volatile matter releases from the coal. The gas generated inside the melter-gasifier contains fine dust particles, which are separated in hot gas cyclones. The dust collected in the cyclones is recycled back to the melter-gasifier through the dust burners, where the dust is combusted with additional oxygen injected through the burners. There are four such dust burners located around the circumference of the melter-gasifier above the char bed. The gas from the melter-gasifier is cooled to the reduction gas temperature (850°C) through the addition of cooling gas. A major part of this gas is subsequently fed to the reduction shaft. The excess gas is used to control the plant pressure. This excess gas and the reduction shaft top gas are mixed prior to the takeover point and is termed as COREX export gas

Figure 2: COREX Process Flow Chart

### 3.4. Commercial units in operation

Korea: POSCO (COREX C-2000 –Capacity: 0.8 Mtpa)

India: JSW Steel, India (2 Units) (COREX C-2000) , ESSAR

South Africa: Mittal-SALDANHA, (COREX C-2000)

China: Baosteel, (COREX C-3000) –Capacity 1.5 mtpa

Table 1: Typical Consumption Figures

Table 2: Typical by-products

### **3.5. Process Comparison Flow Diagram:Figure 3**

### **3.6. Coal Used**

- The coal used in the COREX process must supply heat for the de-volatilisation of the coal, the gasification of the char and the melting of the reduced iron from the reduction shaft. It must also provide sufficient gas to the reduction shaft to reduce the iron ore feed. Coals most suited for use with the COREX process have air dried fixed carbon content from 55 to 70%. Many coals from the Bowen Basin within Queensland are suited to the COREX process and several mines currently supply POSCO's plants in Korea.
- This is to ensure good gas flow within the melter-gasifier and to reduce the carryover of coal and char. The amount of fine coal (minus 5 mm material) that is fed to the COREX process must be minimised. Therefore all coals must be sized or agglomerated before use.
- There are many alternatives to achieve minimum fines content depending on the facilities at the loading port, discharge port and COREX plant. The flexibility of Queensland coal export terminals allows the sizing and blending of coals at the loading port to meet the needs of COREX operators.

### **3.7. Utilization of theCOREX Export Gas**

- The gas generated from the process is used for power generation, for the pellet plant and as a fuel in the integrated plant complex.
- In the chemicals industry the COREX export gas can also serve as a feed stock for many other applications.
- Export gas from the COREX plant is used for the production of direct reduced iron (DRI) in an adjacent DR plant using a MIDREX shaft furnace and LINDE Vacuum Pressure Swing Absorption plant (VPSA) for the removal of CO<sub>2</sub>.

Fig4: Production of DRI

## **4. DEVELOPMENT IN OPERATING PLANTS**

### **4.1. Equipment Changes**

Based on the experience of the producing COREX plants that are operated at very different conditions regarding raw material input and process control and on the experience from the in-house blast furnace know-how, many investigations (e.g. CFD calculations that show the tendencies and effects after implementation of certain charging equipment) were carried out regarding the distribution of the materials charged to the melter-gasifier. Two major optimization points were identified: charging of DRI to the melter-gasifier and charging of coal to the melter-gasifier. Based on the results of the investigations new equipment is designed and applied at single operating COREX plants and will be applied in future COREX plants.

### **4.2. Installation of New DRI Distribution Device**

This new DRI (Direct Reduced Iron) distribution system that is already installed at the COREX. SALDANHA plant is to distribute the DRI evenly onto the melter-gasifier bed surface in a "doughnut" form, at a radius of 2 m to 4 m from the centre. Tests during stable production indicated that the DRI flaps have a dramatic effect on melterperformance. When

the deflection flaps were moved away from the DRI stream, an almost immediate deterioration in melter performance was observed and staves heat losses peaked. Coke addition had to be increased during the tests by 4% to maintain liquid iron temperature.

After the first start-ups of the COREX plants at SALDANHA and JINDAL it was found that charging of coal did not take place as desired. Due to the horizontal discharge speed of the coal at the coal screw outlet, the main coal stream was placed approximately 1 m off the centre on the top of the char bed in the melter-gasifier. By centralizing the coal stream, the situation improved.

Due to the fact that the coal was charged in one stream and no coal distribution took place, major volumes of not-pyrolised coal came into hot areas of the meltergasifier resulting in pressure peaks. After installing a static coal distribution device (coal riffler), that distributed the coal over a wider area of the char bed surface, the pressure peaks situation improved considerably. Based on an almost pressure peak free operation the process pressure and the char bed height could be increased resulting in a more stable hot metal temperature and composition, leading to decreased specific consumption values and smoother process operation.

Already the static coal distribution improves the coal distribution. An even better result will be achieved with a dynamic coal distribution system at COREX SALDANHA that looks similar to a rotating chute of the blast furnace. Such a system will be installed at SALDANHA to achieve a distribution.

Table 3: COREX DRI combination driving factors.

#### **4.3. Production of ELECTRICAL ENERGY**

Regardless of the recycling decision and plant setup, with its excellent calorific value the COREX export gas is best suited for power generation.

When used in a combined cycle power station the export gas is converted to electrical energy with efficiencies up to 46%.

Table 4: Thermal Energy Balance (for 1 Mtpa hot metal)

Table 5:Electrical Energy Balance (for 1 Mtpa hot metal)

Fig 5: Production of Electricity

#### **4.4. Some of the unique features of COREX operation**

Undersized iron ore (size 6-12mm) is being charged directly into the COREX melter-gasifier. It was realized that the surplus heat available at the top of the char bed (stable bed inside melter-gasifier) could be utilized for reduction of iron ore fines. Addition of iron bearing material via the coal line increases the hot metal productivity, generates extra reduction gas for the shaft and helps in controlling the process parameters more uniformly. On a monthly average basis, maximum 15.5% of the total iron bearing material has been substituted by iron ore fines addition.

#### **4.5. Upscaling of COREX Plant: Fig 6**

#### **4.6. Oxygen Distribution insideMelter-Gasifier**

During the start-up of COREX Module-1, the practice was to feed about 15-18% of the total oxygen through the melter-gasifier dust burners and the balance through the tuyeres. With this operational practice, there had been some problems, such as high sludge rate, sudden rise in pressure (pressure peaks), gas channelling through the char bed, rise in melter-gasifier dome temperature, unstable hot metal quality etc. With improved understanding of the process, the oxygen amount through the dust burner was increased gradually and oxygen through tuyeres

was reduced correspondingly and positive results were observed. Presently, about 25 - 30% of the total oxygen is passed through dust burners and the balance through the tuyeres. In this process a major share of the metallurgical reactions, such as, residual reduction, calcination etc. are carried out in the upper part of the char bed which results in stable char bed condition, reduction in sludge rate and better hot metal quality.

#### **4.7. Selection of Non-Coking Coals**

JVSL is importing coals from Australia, South Africa and China. All these coals have been initially tested in the laboratory and later found to be suitable for COREX operation. Over last two years of operation, JVSL COREX has used more than ten different types of coals either individually or as a blend of two or three types of coals. Wide ranges of volatile matter (20- 34%) and coal ash (9-12%) have been tried in COREX. Additionally, other physico-chemical properties such as the strength and the reactivity of the coal char also varied widely. A high volatile coal is blended with low volatile coals so as to maintain the total volatile content around 30%. On similarit is preferred to blend high ash content, with low ash coal to maintain a moderate content in the coal blend. The mean particle size of the coal blend has significant influence on the process and is closely monitored besides other quality parameters.

### **5. FINEX TECHNOLOGY**

It is an optimized fine-ore reduction process for the direct utilization of the world's vast resources of low-cost iron ore fines for the production of iron. The FINEX smelting-reduction process based on the direct use of non-coking coal and fine ore is perhaps the most exciting iron making technology on the market today. This is a process with great potential with regard to productivity and the low cost production of hot metal.

In this process fine iron ore is preheated and reduced to fine direct reduced iron (DRI) in a three or four stage fluidized bed reactor system. The upper reactor stage serves primarily as a preheating stage. In the succeeding stages the iron ore is progressively reduced to fine DRI. The fine DRI will be compacted and then charged in the form of hot compacted iron (HCI) into the melter-gasifier. The charged HCI is subsequently reduced to metallic iron and melted. The heat needed for the metallurgical reduction work and the melting is supplied by coal gasification with oxygen. The reduction gas, also produced by the coal gasification, is passed through the fluidized bed reactors. The generated FINEX export gas is a highly valuable product and can be further used for DRI/HBI production, electric energy generation or heating purposes. Fig 7

#### **5.1. Benefits of the FINEX process -**

- (i) Favourable economics in comparison to the blast furnace route,
- (ii) Environmental benefits due to savings in resources and energy, as well as lower emissions,
- (iii) Direct utilization of non-coking coal,
- (iv) High valuable export gas for a wide range of applications in metallurgical processes and energy production,
- (v) Production of hot metal with similar quality to the blast furnace,
- (vi) Reduction of process steps.

Fig8: Curve comparing traditional blast furnace with emerging FINEX Tech.

### **6. ECOLOGICAL REGULATION**

- Efficient recycling of metallurgical waste material.
- Production of valuable export gas for Power generation is an isolated area.

- COREX plant emissions contain only insignificant amounts of NO<sub>x</sub>, SO<sub>2</sub>, dust, phenols, sulphides, and ammonium. Emission values are already far below the maximum values allowed by future standards. Also, waste-water emissions from the COREX process are far lower than those in the conventional blast-furnace route. These environmental features are key reasons for the attractiveness of the COREX process.
- In countries like the US, Canada, Japan, Australia and in Western Europe industry is confronted with regulations regarding environmental emissions in the production of iron. Coke ovens and sinter plants are most affected. The environmental advantage of smelting reduction technology over the conventional route is generally articulated by all actors involved in developing smelting reduction technology.

Fig 9: Emission comparison- Blast furnace / COREX

## 7. CONCLUSION

- The performance of COREX& FINEX process indicates brighter future smelting-reduction process. It has carried out a number of developments within a short span of operation and is constantly striving for further improvements. The present pace of developments would definitely pave the way towards the lower cost steel production.
- Today, direct smelting is a much sought-after prize. The traditional blast furnace route for iron making is coming under increasing pressure-environmental and economic. Many have tried to develop direct smelting technologies, but it appears to be moderately difficult, certainly more so than one might expect.
- Out of many processes COREX & FINEX are considered to be most environment-friendly technology for iron making process.

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## FIGURES AND TABLES:

Fig 1:Schematic lay-out Of Smelting Reduction Technology.

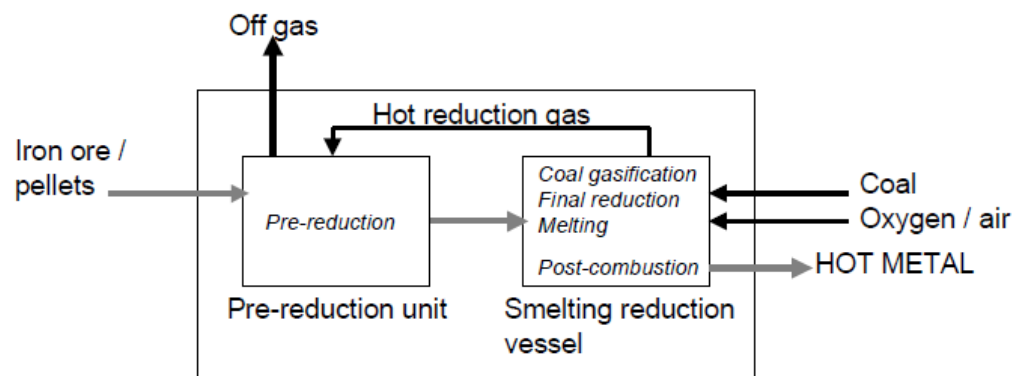


Fig 2 :COREX Process flow chart

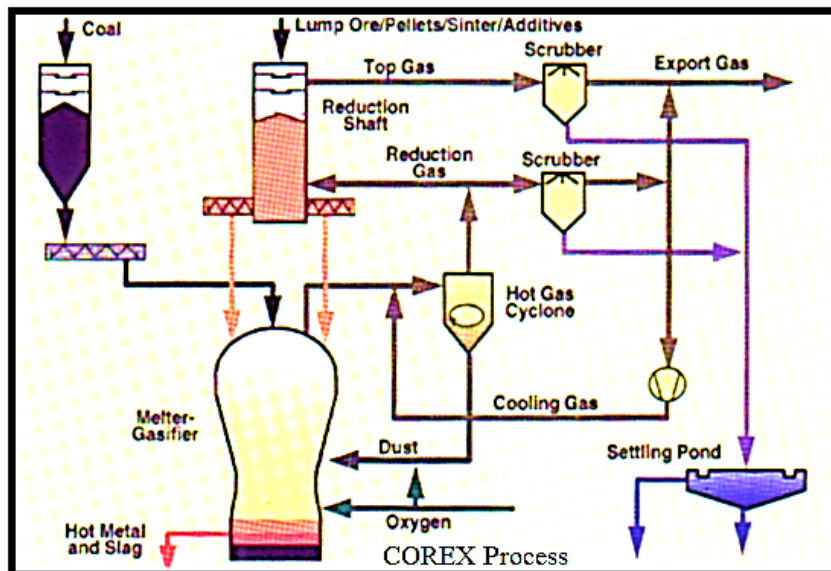
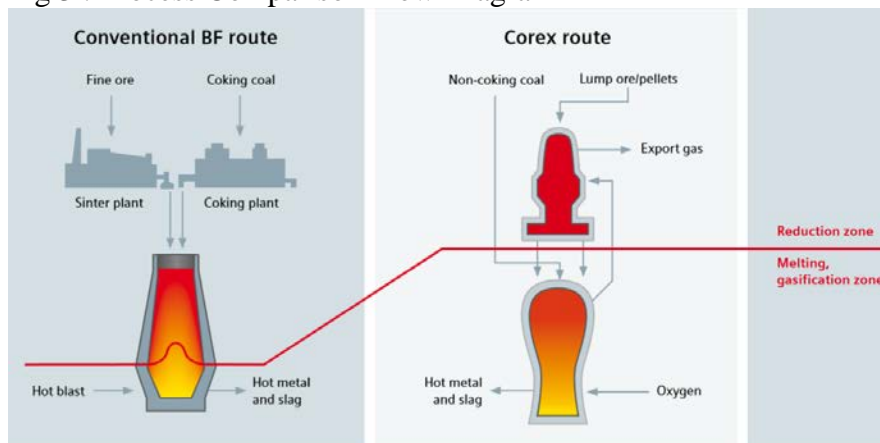


Fig 3 : Process Comparison Flow Diagram



Process comparison - Blast furnace/SIMETAL Corex

Figure 4 :Production of DRI

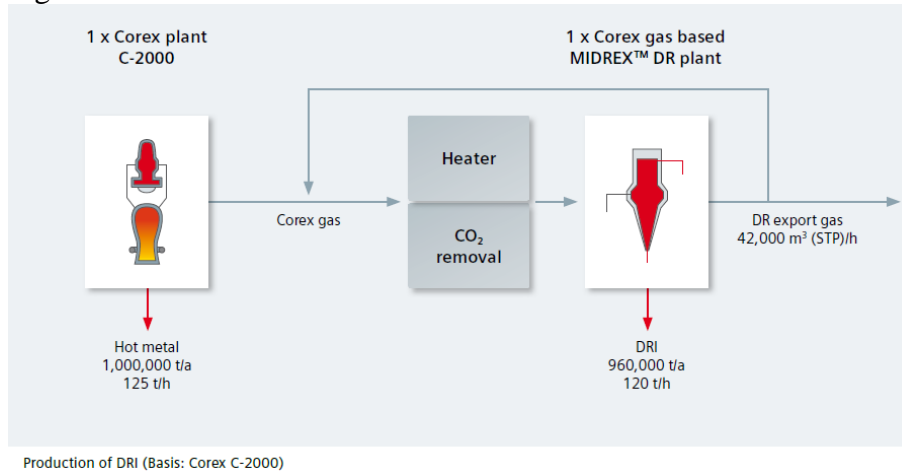


Figure: 5 : Production of Electricity

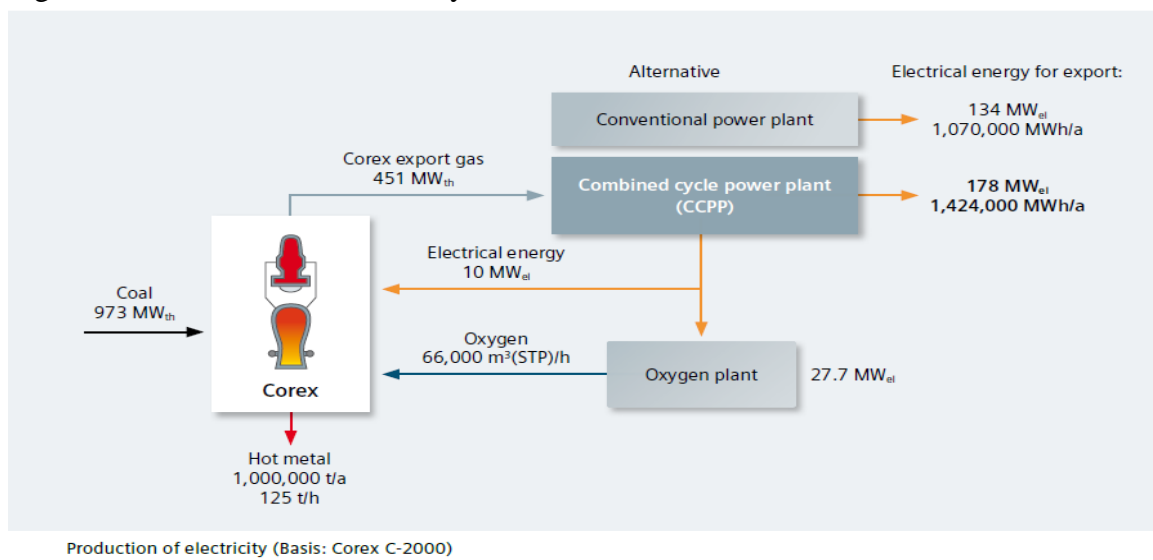


Figure 6: Upscaling of COREX Plant

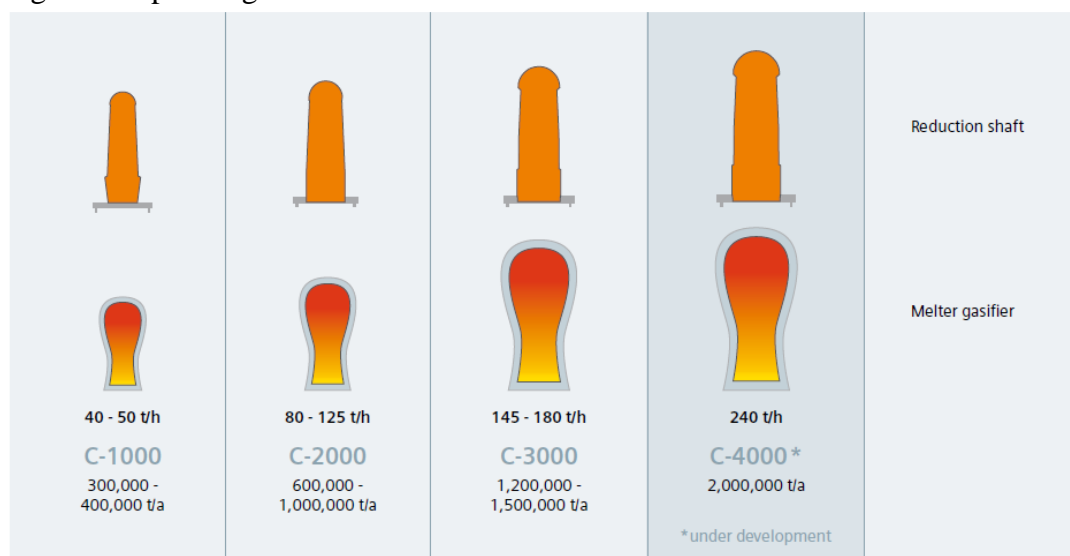


Figure 7: FINEX Technology

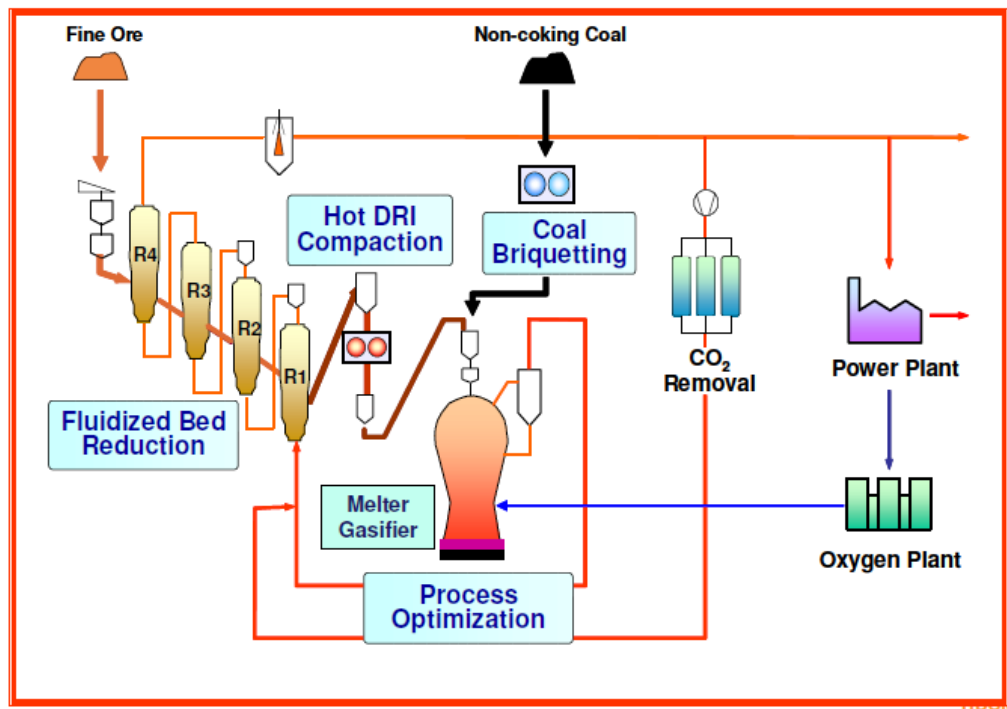
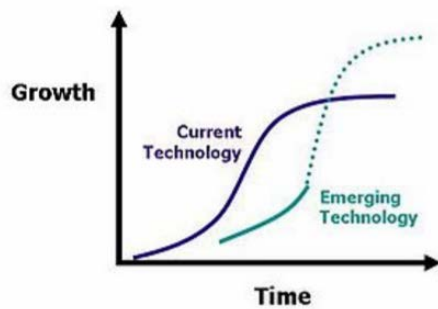
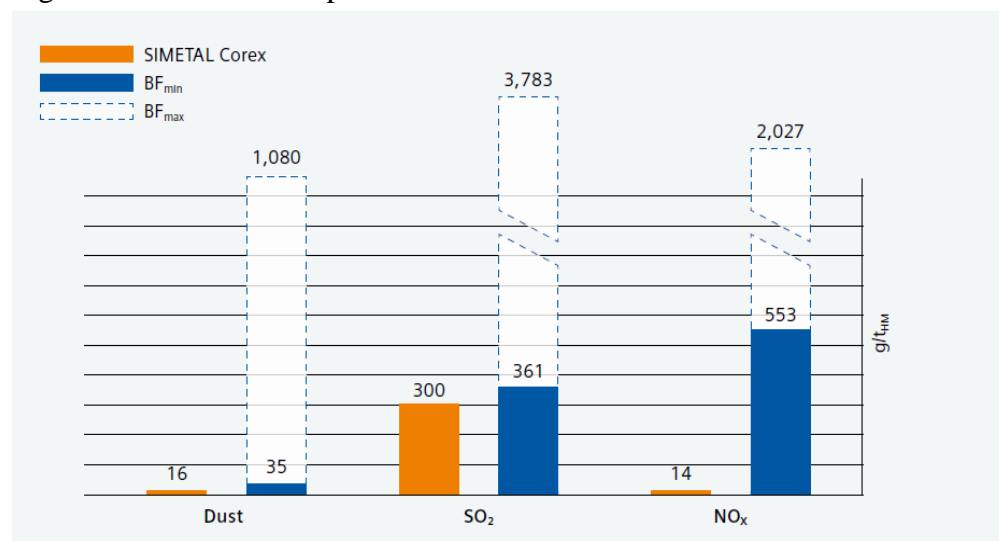


Figure 8 :Curve comparing traditional blast furnace with emerging FINEX Tech



S-Curves comparing traditional blast furnace with the emerging FINEX technology

Figure 9 : Emission comparison- Blast furnace / COREX



Emission comparison - Blast furnace / SIMETAL Corex, (Source:BAT for the production of iron and steel – EU Joint Research Center)

Table 1: Typical Consumption Figures

	Standard (kg/t <sub>HM</sub> )	Recycle option (kg/t <sub>HM</sub> )
Fuel <sub>dry</sub>	940	770
Additives	265	185
Oxygen	520	450

Table 2: Typical by-products

	Standard	Recycle option
Slag	340	265 (kg/t <sub>HM</sub> )
Export gas	1650	1410 (m <sup>3</sup> /t <sub>HM</sub> )
	8100	7500 (kJ/m <sup>3</sup> )

Table 3: COREX DRI combination driving factors

DRI Production	1000 (kg/t <sub>HM</sub> )
Fuel <sub>dry</sub>	530 (kg/t <sub>iron</sub> )
CO <sub>2</sub> emission	<1250 (kg/t <sub>iron</sub> )

Table 4: Thermal Energy Balance (for 1 Mtpa hot metal)

Plant Setup	Standards (MW)	Recycle option (MW)
Energy Input	915	790
Energy Consumption	470	450
Energy output	445	340

Table 5: Electrical Energy Balance (for 1 Mtpa hot metal)

	Standards (MW)	Recycle option (MW)
Power Generation	205	155
Power Consumption	35	45
Power output	170	110